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The marine environments of the Dampier Archipelago

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Abstract

The Dampier Archipelago is an inundated landmass similar in topography to the present hinterland. A gently rising undulating submerged plain now occurs 5-20 m below mean sea level (e.g. Mermaid Sound). Inundated hills and ridges rise up from this plain, the lowest forming subtidal rocky reefs, the highest forming the numerous islands of the archipelago. Inundated valleys form the embayments, straits and channels of the archipelago.

Much of the coastline is igneous rock of Precambrian age. Pleistocene limestone is locally plastered onto this rock. Overlying all rock types is a veneer of varying thickness of sand, gravel or mud deposits. Each of these substrate types occurs in a range of locations which vary according to height above or below mean sea level, topographical configuration and exposure to waves and currents. Consequently there is a wide range of geomorphic units within the archipelago which include intertidal and subtidal rocky shores, intertidal and subtidal limestone pavements, intertidal flats, intertidal beaches and subtidal plains.

Habitats are intimately linked to geomorphic units and each habitat type supports its own characteristic assemblage of marine organisms. Biotic assemblages have been broadly grouped into categories based on the most common or noticeable species within the group. These assemblages are: oyster-barnacle, coral, mangal, *Notocallista*-echinoderm, demersal fish-echinoderm-crustacean, *Donax*-crustacean, *Uca*-cerithid, *Mictyris*, *Uca-Macrophthalmus*, xanthid-sponge, *Ocypode*, seagrass, algae, embayment fish, pelagic fish-plankton.

Introduction

The coastal environment of the Dampier Archipelago (Fig. 1) is largely undescribed. The area is mentioned in a number of regional survey reports (Jutson 1950; Burbidge and Prince 1972) and portions of the coral reefs of the outer archipelago have been studied previously by the Western Australian Museum (Wilson and March 1974). Recent research in the area has provided data on natural history aspects of the region and this paper presents some of the results. As such the paper provides both the background for a series of papers currently in preparation which will describe each of the major habitat/biotic assemblages and sedimentology in greater detail.

In this study the Dampier Archipelago is placed in its regional context. The basic habitats and biotic assemblages of the archipelago are described and related to a framework of geology, geomorphology, stratigraphy, substrates and oceanography. The distribution of the habitats and biotic assemblages is shown to be highly variable because of the stratigraphy, the distribution of geomorphic units, aspect (exposure to wave climate), surface processes (e.g. sedimentation versus erosion) and oceanography.

Methods

A variety of methods was used and a range of sites was studied to collect data for this paper. The regional coastal environment and selected small areas were studied by use of aerial photographs and supplementary on-ground surveys. Within the Dampier Archipelago, study sites and transects were located to sample as wide a range as possible of variation in habitats and biotic assemblages.

Subtidal transects (Fig. 2A) along rocky shores were established by a weighted line (marked in 5 m intervals) which extended from the tidal zone to offshore for 100-125 m. Observations on geology, substrate and biota were made by diving and data were recorded on waterproof data sheets supplemented by photography. Intertidal rocky shores and intertidal flat areas were selected for detailed mapping of morphology, habitats and biota (Fig. 2B); within these areas, transects and sampling sites were established to document geology, substrates and biota; observations were recorded on data sheets supplemented by photography. At numerous sites on the intertidal flat, the shallow stratigraphy also was explored by cores (up to 2 m) and auger.

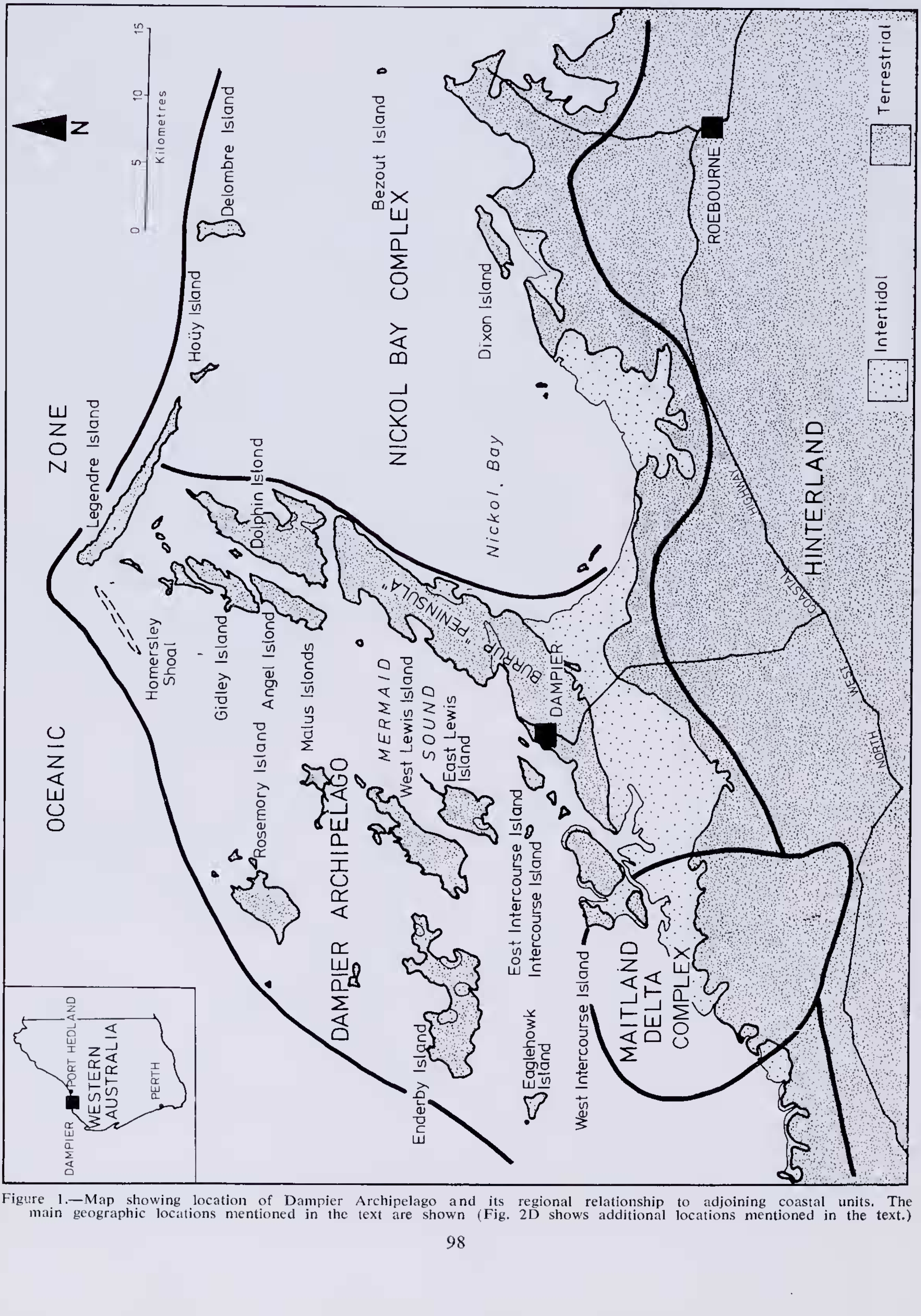


Figure 1.—Map showing location of Dampier Archipelago and its regional relationship to adjoining coastal units. The main geographic locations mentioned in the text are shown (Fig. 2D shows additional locations mentioned in the text.)

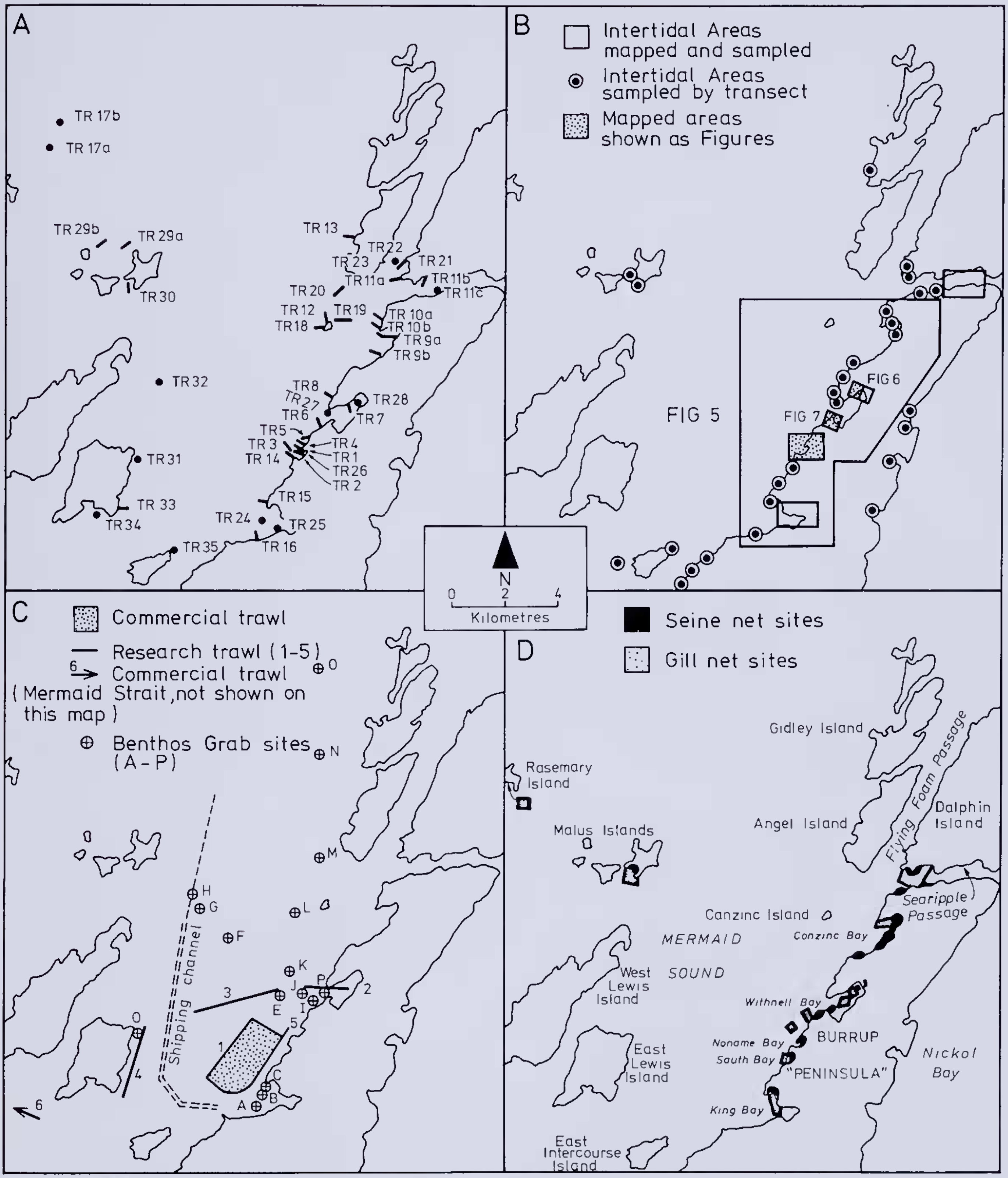


Figure 2.—Sampling sites. A.—Location of subtidal transects. B.—Location of intertidal areas mapped and sampled. C.—Location of trawls and benthic grabs. D.—Location of fish netting sites.

Deep subtidal offshore areas were investigated by commercial trawls, research trawls, benthos grabs and by underwater inspection (Fig. 2C). In August 1978 the catches of a commercial prawn trawler were examined on 2 nights to determine species diversity in the benthic fauna. This information was supplemented by collecting fauna from a small trawl (mouth aperture 5.2 m, mesh 5 cm) towed behind a research vessel. A Van Veen benthic grab was used to collect sediment and biota samples (five or more replicate samples per site) from various subtidal sites (Fig. 2C).

Fish were collected by gill nets, seine nets (Fig. 2D) and by underwater observation. The gill nets were designed to sample fish of all sizes on both the surface and the sea floor. Seine netting was carried out in a number of different habitats (viz exposed beaches, protected beaches, low tidal flats). Underwater observation of fish also was carried out mainly on coral reef environments.

Most of the biota samples have been lodged with the Western Australian Museum. Sediment (substrate) samples were visually described by binocular microscope and routinely sieved for granulometric analyses. Selected samples were thin-sectioned for petrographic analyses.

Regional setting

The Dampier coastline is situated in the Pilbara region, termed Pilbaraland by Jutson (1950). It is unique in that the coastal area borders a hinterland that is situated in an arid climate. The distinctive landforms of the Pilbara form the architecture of the nearshore marine environment. The combination of tidal regime, wind-generated waves and archipelago-style coastal geomorphology also makes the area distinct oceanographically.

Climate

The climate of the Pilbara region is tropical and arid (Gentilli 1972). Table 1 presents relevant climatic data. The area is also subject to periodic cyclones during the period December to April. Coleman (1970) shows that a cyclone passes within 100 km of the coast every 2-3 years. These cyclonic disturbances are responsible for heavy rainfall as well as increased wave action in coastal zones.

Regional coastal units

The coastline around Dampier can be conveniently divided into five main regional units based on general geomorphology and oceanography (Fig. 1). These units are:—

Hinterland, Oceanic Zone, Nickol Bay Complex, Maitland Delta Complex and Dampier Archipelago.

Throughout this paper the above names are used to denote the designated coastal unit and not geographic localities.

Hinterland.—The hinterland is the landmass which borders the marine complexes. It is composed of rocky hills, ridges, colluvial slopes, alluvial flats, river courses, sandplains and subaerial portions of deltas. The bedrock geology of the hinterland consists of folded metasedimentary and metavolcanic rocks and irregularly ovoid domes of granite (Geological Survey of Western Australia 1975). Regional topography is controlled by jointing and fracture systems. Thus landforms reflect trends of the geological grain of the country as well as the weathering and erosion of fracture systems. Low plains consist of sand, alluvial wash and in situ soil. Hills and ridges are flanked by slopes of boulder and coalescing colluvial fans. Locally, along the coast, the hinterland is composed of aeolian sand formed by shoreward transport of inner-shelf marine sand. Few major rivers drain the Pilbara region; these flood only sporadically for short periods. The rivers contribute alluvium to the extensive plains and form deltas at their mouths.

The margin of the hinterland with marine geomorphic units is locally sharp and delineated by steep slopes or dune lines. In other areas it is irregular and diffuse where low-lying supratidal flats, extensive high tidal salt flats, alluvial valleys and deltaic lobes form a broad zone of contact.

Oceanic Zone.—The Oceanic Zone, characterized by deep open oceanic waters (> 20 m), forms the inner part of the north-west shelf. It is sharply demarcated from the Dampier Archipelago and Nickol Bay Complex by a steep slope where the seafloor descends to depths of 30 (and more) metres. This junction is often delineated by a line of submerged rocky reefs or coral reefs, or shoals that locally protrude above water surface, e.g. Hamersley Shoal and Legendre Island. Regional bathymetric charts indicate that

Table 1

Mean monthly climatic data for Dampier †

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Daily Maximum Temperature (°C)	35·0	37·1	36·0	33·6	29·2	26·3	26·3	26·8	29·7	32·6	34·6	35·3
Daily Minimum Temperature (°C)	26·3	26·4	25·8	22·0	17·8	15·1	14·0	14·9	16·5	19·5	22·1	25·4
Rainfall (mm)	29	57	41	14	70	62	14	10	*	0	2	16
Raindays (No.)	4	3	6	1	4	5	4	2	0	0	1	3
Evaporation (mm)	354	311	325	283	224	198	193	228	291	348	379	384

† Data from Bureau of Meteorology (1975). * Value is between 0·1 and 1·0

within the Oceanic Zone there are several large-scale platforms or terraces demarcated by relatively steeper slopes. Locally rocky islands and coral reefs protrude above the shelf surface. The seafloor physiography and substrate is one of flat, featureless limestone pavements, terraces and sand/gravel veneers (Woodside Petroleum Development 1978).

Nickol Bay Complex.—Nickol Bay is a large, shallow marine embayment (35 km x 20 km) and is a coastal portion of the north-west shelf. Bathymetric charts indicate a uniform gentle seafloor inclination; the seafloor is 20 m deep at the north margin and progressively shallows to intertidal at the south. Few islands or rocky reefs break this monotonous surface (e.g. Haüy and Delambre Islands to the north). The shoreline components of the Nickol Bay Complex include mudflat embayments, rocky shores, limestone pavements, sand beaches and mangal flats. The Nickol Bay Complex is separated from the Dampier Archipelago by the chain of islands which includes Burrup "Peninsula"* and Dolphin Island.

Maitland Delta Complex.—The Maitland Delta Complex is a deltoid coastal lowland; it is a drowned sandplain system (which has locally been overlain by alluvial wash and tidal sediments) interspersed with tidal mud deposits and sand ridge systems. The delta area appears to be underlain by a widespread sheet of Pleistocene limestone.

The entire lowland system has formed as a result of deltaic sedimentation during the Quaternary. The interplay between tidal sedimentation (mud), alluvial input, sand bar/ridge sedimentation, tidal erosion and sand plain degradation has developed a variety of tidal and marine habitat types that are unique to this delta complex.

Dampier Archipelago.—The Dampier Archipelago is a system of islands, rocky reefs, coral reefs, shoals, channels and straits. It also forms the coastal portion of the north-west shelf. This unit is treated in detail in the next section.

Dampier Archipelago

Oceanography and meteorology

The coastline of Dampier Archipelago has large semidiurnal tides (Easton 1970). Mean spring range is 5.6 m; mean neap range is 1 m (Australian Tide Tables 1981). Tidal currents in embayments locally reach a maximum speed of 50 cm/sec during spring tides, but for the most part data on tidal currents are sparse.

Meteorological and oceanographic characteristics of the Dampier Archipelago are not well known but limited data (Woodside Petroleum Development 1978) show that the environment has variable waves. Long period swell from north, north-west and west impinges mainly on the exposed portions of the outer islands. Southerly facing coasts, embayments, straits and passages between islands are protected from swell. Most waves are generated by local winds and wave direction follows wind direction, coming mainly from north-east, east, south-east and north-west during winter and from south-west, north-west and south-east during the summer. Wind-generated waves are small, generally less than 1.3 m height. Water circulation patterns are not known in detail but it appears that mixing is dominated by tidal currents, waves and winds (Woodside Petroleum Development 1978).

The open waters of the Dampier Archipelago show normal oceanic salinity and supersaturation with oxygen. Coastal and nearshore areas of the archipelago exhibit the same average values of salinity and dissolved oxygen as the offshore areas. However there is marked variation in the salinity and dissolved oxygen levels of the interstitial and ponded waters of tidal flat areas. Water temperatures on the north-west shelf and adjacent Pilbara coast are highest in summer and lowest in winter (ranging from between 19°C to 32°C) in response to intensity of solar radiation.

The turbidity of the water has been observed to be variable in time and place. Turbidity is due to suspended particulate sediment, organic detritus and plankton; the relative importance of each component depends on tidal cycle, wave action, season and location. At some times of the year, notably spring to summer, plankton blooms contribute locally to turbidity. There is also contribution from the Maitland River during floods, and Nickol Bay during spring tides.

Morphology

The Dampier Archipelago is a large marine area characterised by groups of islands, rocky reefs, coral reefs and shoals that rise from a general deep-water plain. The Dampier Archipelago may be subdivided into several morphological units characterised by depth, general physiography and component materials (rock and sediment). These units form the framework for broad scale classification of types of coastline. The units are: submarine plains, islands, rocky reefs, coral reefs and shoals, and channels and straits.

Submarine plains.—The submarine plains occur in deep water and form approximately 60% of the Dampier Archipelago. Bathymetric charts indicate that on a regional basis the plains are gently sloping features about 5 m deep below ILWS near the hinterland and 15-20 m deep at the northern margin. The seafloor is underlain either by extensive pavements of limestone, or vast sheets of shell gravel, sand and muddy sand/gravel.

Islands.—Rising above the general level of the submarine plain are partly inundated hills and ridges. These comprise the numerous islands that form some 15% of the surface area of the archipelago. The disposition, geometry and composition of the islands reflect regional geological lithology and fracture patterns (Fig. 3). Major north-east trending rock units form resistant ridges, flanked by valley systems developed on the more weathered rocks; marine inundation has resulted in north-east-trending chains of islands of essentially similar rock types.

* The term "Burrup Peninsula" is used by Lands and Surveys of Western Australia, but technically the "peninsula" is an island. Several causeways now join the Burrup area to the mainland (hinterland), but in the past access to the island was across tidal flats (which now underlie solar salt-production ponds) and at high tide the area was cut off totally from the hinterland.

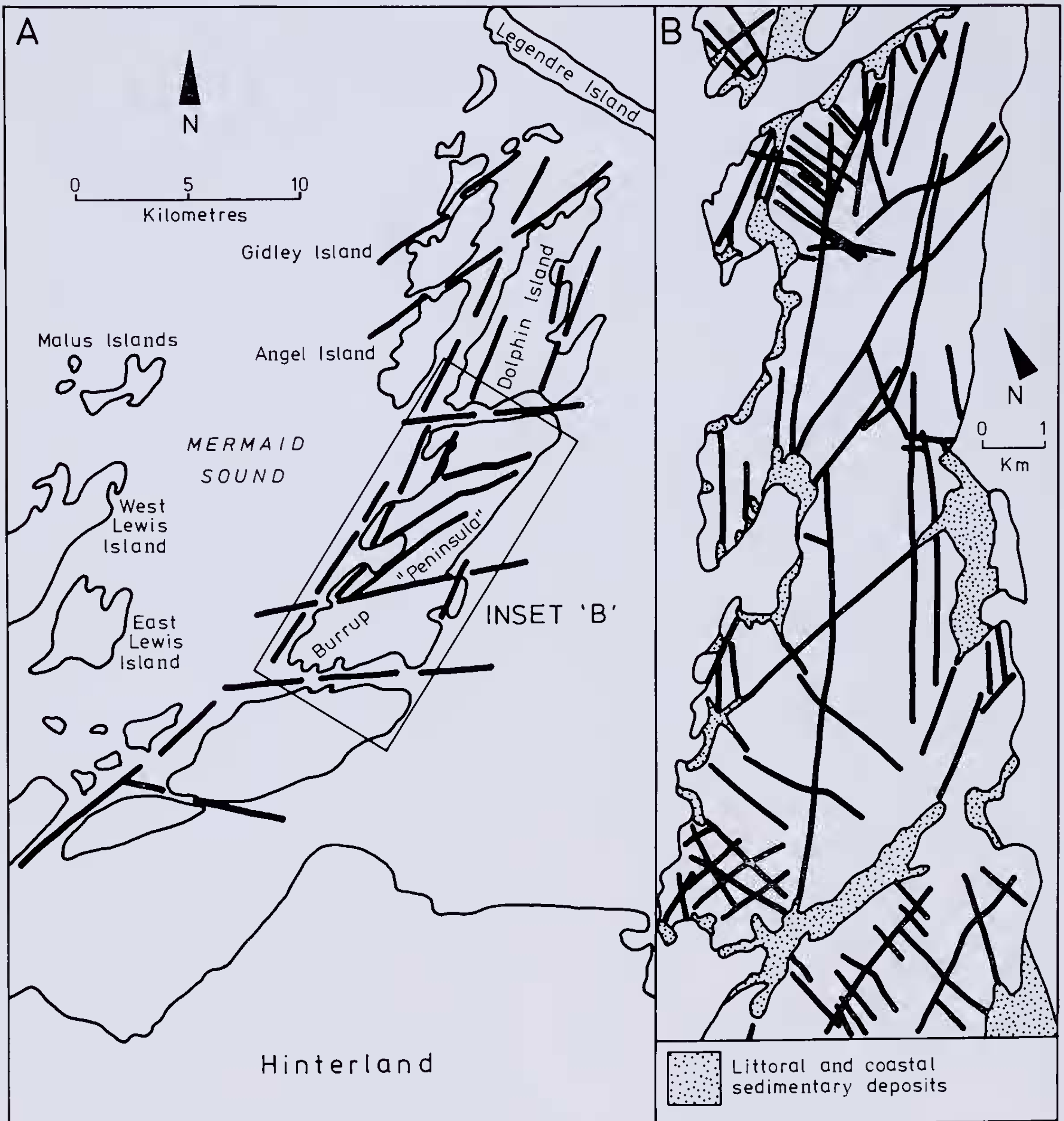


Figure 3.—A.—Major fracture patterns that determine the geometry and disposition of islands, passages and straits. B.—Detailed map showing major fracture patterns that determine shape and orientation of embayments.

Islands essentially have 3 terrestrial and 4 marine components. The terrestrial components are similar to the hinterland and include rocky terrains, valley systems and sand dunes. The marine components are rocky shores, protected embayments, exposed embayments and submarine slopes. Rocky shores are the dominant marine components. The protected embayments are the modern tidal flats and shallow subtidal bays that occur as discrete units along the margins of islands. Exposed embayments are the modern sandy (beach) coves. The slopes adjoining islands descend from low tide levels down to subtidal depths of 5 to 10 m, frequently with a moderately steep inclination. Submarine slopes of islands are similar to sub-aerial slopes of hills and ridges in inclination, components (boulders, pebbles) and disposition, and probably represent inundated subaerial scree deposits.

Rocky reefs, coral reefs and shoals.—Submerged to tidally-submerged hills and ridges rising up from the submarine plain are the present rocky reefs. Some are colonised by corals to form coral reefs. The disposition, geometry and composition of rocky reefs also reflect regional lithology and fracture patterns.

Shoals are the shallowly submerged accumulations of sand and gravel derived by breakdown of both modern coral reefs and older limestone, and comprise about 15% of the surface area of the archipelago. They frequently form connections between the islands and coral reefs of the archipelago, occurring on the leeward side of islands or as aprons around islands. Locally shoals are sediment accumulations on shallowly submerged rocky reefs or limestone pavements. Many shoals become partly emergent on a falling tide and their surface is mobile during flood and ebb tide.

Channels, straits and embayments.—Channels, straits and embayments are inundated valleys and lowland systems. These can be traced into present terrestrial drainage systems whose disposition also largely is controlled by either the regional fracture (or joint) trends (Fig. 3) or location of weathered dolerite dykes which intruded these fractures (Geological Survey of Western Australia 1980). The regional fracture trends are oriented north-west, east-north-east and north-north-west and have resulted in major valley systems that segment the terrain into its component islands and embayments (Fig. 3). All islands, straits and embayments reflect this regional pattern to some extent.

The inundated valleys, embayments or straits are filled with sedimentary materials to varying degree. The King Bay embayment is largely filled with soils, limestone and marine sediments to levels of high tide and low supratidal; in contrast Searipple Passage is filled by limestone to levels of low neap tide, and Flying Foam Passage appears unfilled.

Substrate materials of the Archipelago

Geological materials comprise the substrate types that differentiate the various geomorphic units. Substrates also play a large role in determining distribution of habitat and determine the composition and distribution of the biota. The main geological materials of the Archipelago are: igneous rock, limestone, sand/gravel and mud. The stratigraphic array of these materials is summarised in Figure 4 and their distribution is summarised in Table 3. This shows that a variety of Holocene sediment types overlies Pleistocene and Precambrian rock units.

Precambrian igneous rock forms the core structure of islands and rocky reefs. In the marine environment it is hard, crystalline, smooth and not readily destructible. The rock forms large smooth surfaces, or creviced fissured surfaces. It also forms bouldery accumulations (boulder frame with interstitial sand and/or mud) on slopes. Limestone also may comprise the material of islands and rocky reefs typically as an external or peripheral plaster to a core of igneous rock. It also forms extensive pavements in tidal zones and deep-water plains. As a rock type it is a bedded and laminated, semi-indurated quartz skeletal sand. In the marine environment it erodes readily to thick slabs and boulders, and forms creviced, honeycombed, irregular to hummocky surfaces upon which there may be a patchy mobile veneer of unconsolidated sand.

Sand and gravel are derived by breakdown of rocks and calcareous skeletons of biota. The sediments occur as extensive veneers over vast areas of igneous rock and limestone sea bottoms in deep water. Additionally these sediments occur as (1) offshore mound-like shoals, (2) subtidal to intertidal sheets, (3) shoreline ribbon deposits (beaches, bars, spits), (4) shoreline wedges in embayments and (5) small deltaic accumulations in shallow water. Gravel is either granule- to pebble-sized calcareous skeletal or granule- to boulder-sized lithoclast debris; sand and mud may occur interstitial to the gravel frame. Sand consists mainly of fine- and medium-size fractions. These sands range from quartz/lithoclast/skeletal types to dominantly skeletal types; mud also may occur interstitial to the sand grains and thus sandy sediments range from cleanly washed in high energy environments to muddy on tidal flats and subtidal plains.

Mud is transported into the marine environment by fluvial processes, or is eroded from older sedimentary deposits, or is biogenically generated. It occurs as sheet-like veneers in deep water over igneous rocks and limestone, and when mixed with sand also forms wedge-shaped to ribbon-shaped shoreline accumulations.

Geomorphic processes

The large scale coastal morphology was developed by subaerial arid-zone weathering prior to the Quaternary marine transgressions. Following the post-glacial transgression, today various parts of the archipelago are undergoing either erosion or sedimentation. These processes are developing the wide range of geomorphic surfaces (and units). Marine erosion is dominant in developing the small scale structure of most coastline types either by causing retreat or by exhuming buried stratigraphic units. Sedimentation is less important and has resulted in only localised accumulations. Sites that are not the result of either erosion or sedimentation usually are relic surfaces. These are gravel pavements or bouldery slopes that are marine-inundated terrestrial surfaces (valley alluvium, sheet colluvium and scree slopes).

Erosion.—There are 5 main geomorphic features that are the result of coastal erosion: cliffed shores, eroded limestone pavements, undercut and collapsed mangrove trees, eroded salt flat, and exhumed stratigraphic units.

Cliffs cut into limestone and igneous rock are a dominant feature of the shoreline of the Dampier Archipelago. The cliffs are formed by wave attack, biological erosion, undercutting and mass wasting. Marine erosion also is a major factor in developing the widespread limestone pavements. By a combination of tidal scour, wave attack, biological erosion and solution the limestone is degraded to an irregular to hummocky, internally honey-combed pavement that is covered by a sand/gravel veneer (itself the product of the eroding limestone).

Tidal scour and tidal-creek headwater erosion are resulting in degradation of high-tidal salt-flat surfaces. There is development of small cliffs, residual high-level mesaforms (<30 cm high) and shallow channels. Tidal scour and wave attack progressively has exposed mangrove roots and has undercut mangrove trees along the seaward edge of many mangrove belts. As a result there has been a slow but net coastal retreat. Continued long-term erosion in many

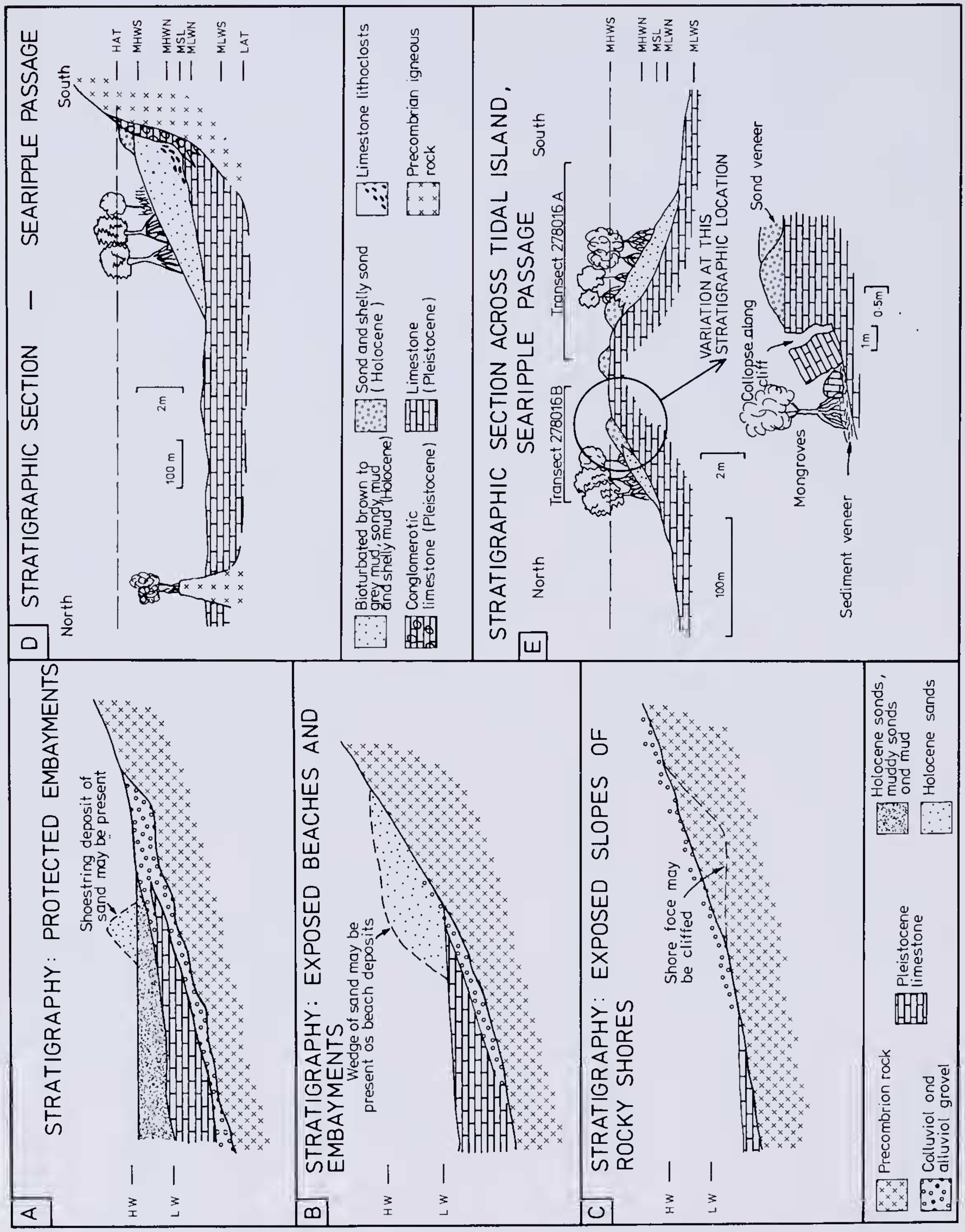


Figure 4.—A, B, C.—Summary of stratigraphic relationships in Dampier Archipelago. These relationships have formed as a result of erosion or sedimentation. The range of stratigraphic material in the profile determines the variation in substrates. D, E.—Details of stratigraphic relationships at two localities in Searipple Passage.

areas has resulted in removal of Holocene sedimentary deposits and the tidal zones now expose exhumed unconformity surfaces and Pleistocene stratigraphic units: these include gravel pavements (colluvial gravel sheets or alluvial gravel deposits) and calcreted limestone pavements.

Sedimentation.—There are 5 major sites of sedimentation in the Dampier Archipelago. These are: tidal flat accumulations and associated spits within embayments, beach-dune deposits, coral reefs and associated shoals, subtidal plain deposits, and supratidal/high-tidal deposits. Some of these accumulations have resulted in development of a shoaling stratigraphic sequence. Other deposits merely occur as a veneer on an unconformity.

Sedimentation within embayments has resulted in a wedge-shaped tidal deposit whose internal stratigraphy reflects progradation (Figs 4 and 6). Low tidal flat sediments are overlain by bioturbated and root-structured mud and muddy sands formed under mangrove cover, and this is overlain by salt-flat deposits. Depending on location relative to headlands, a sand or shelly sand spit (or chenier) may overlie landward parts of the tidal-sediment wedge. These tidal deposits typically rest on a shallowly buried unconformity surface cut into Precambrian rock, or colluvial soil, or Pleistocene limestone.

Sediment locally accumulates in exposed (beach) coves and embayments. Generally the accumulation is laterally limited by adjoining headlands. The deposits typically pass upslope into beachridge and dune deposits. Most beach/beachridge/dune accumulations typically overlie Pleistocene limestone at shallow depth.

Coral reefs locally have built up substantial deposits in the outer part of the archipelago. These reefs are encrusting on either Precambrian rock or Pleistocene limestone foundations. More typically, coral reefs form only thin encrustations on bedrock substrates; the larger coral reefs are associated with substantial build-ups of sand (shoals) derived from the coral and underlying rocks.

Deeper water subtidal-plain surfaces (usually limestone pavement) are covered by sand, shell gravel and mud. These deposits are accumulating by in situ biota contribution, redistribution of relic sediments, breakdown of limestone and fall-out of suspended mud. The deposits usually are thin (< 1 m).

Tidal erosion and dispersion as well as wet season sheet wash of the sand plain sediments along the supratidal zone results in a sheet of sand distributed over the upper edge of high tidal flats.

Geomorphic units

Numerous geomorphic units are differentiated within the Dampier Archipelago mainly on substrate type, geometry and substrate surface and tidal level. The units have developed by a combination of factors which include: erosion versus sedimentation, underlying stratigraphic sequence, tidal level, wave action and ancestral (pre-Holocene) physiography. The geomorphic units are: (1) Intertidal rocky shore, (2) Subtidal rocky shore, (3) Intertidal limestone pavement, (4) Subtidal limestone pavement, (5) Intertidal flats, (6) Intertidal beaches, (7) Subtidal shoals, and (8) Subtidal plains.

A description of the geomorphic units, their distribution and their occurrence within regional coastal morphology types is presented in Table 2. These

Table 2

Geomorphic units and their distribution

Unit	Description	Distribution	Relationship to physiographic units
Intertidal rocky shore	steep, cliffed shore cut into igneous rock; cliffs and sloping pavements alternate with bouldery shores; zone is inundated by tides	developed along exposed portions of islands; elsewhere developed as headlands within embayments of islands	margins of islands: both exposed shores and embayments
Subtidal rocky shore	as above; bouldery slopes more common; zone extends from low water to 8 m depth	as above	subtidal margins of islands, slopes and reefs; some embayments
Intertidal limestone pavement	gently to moderately inclined limestone pavement inundated by tides; cliff may be developed at about HWM	developed locally along rocky portions of embayments of islands	along margins of embayments of islands
Subtidal limestone pavement	gently inclined limestone surface extending from low water to over 5 m depth	developed in embayment of islands as subtidal extensions of tidal limestone pavement	subtidal margins of channels, embayments and islands
Intertidal flat	gently inclined surface underlain by muddy to sand sediment and exposed by tides	developed in protected parts of embayments of islands	within protected embayments of islands
Intertidal beach	moderately inclined surfaces underlain by sandy to gravelly sediment and exposed by tides	developed in exposed embayment and coves of islands	within exposed embayments and coves of islands
Subtidal shoal	large-scale hummocky to featureless subtidal mounds of sand	developed in northern parts of the archipelago	comprise the shoals
Subtidal plain	extensive, featureless subtidal surface occurs at water depths of 0–20 m, more usually 5–15 m; gradually deepening to north	developed in deep water of straits and shallow to deep subtidal of embayments	comprise the submarine plains and subtidal parts of embayments

Table 3

Habitats within geomorphic units

Geomorphic unit	Habitat	Substrate
Intertidal rocky shore	cliffed shore fissured rock pavement or slope bouldery shore	igneous rock and their bouldery deposits
Subtidal rocky shore	fissured rock pavement or slope bouldery shore gravel pavement	igneous rock and bouldery deposits
Intertidal limestone pavement	limestone cliff limestone pavement	limestone
Subtidal limestone pavement	limestone pavement	limestone
Intertidal flats	salt flats sand flat gravel pavement muddy sand flat shoal tidal creek spit	sand gravel muddy sand mud
Intertidal beach	beach ridge beach	sand
Subtidal shoal	sand flat	sand
Subtidal plain	(muddy) sand/gravel sheet locally limestone pavement	sand gravel muddy sand limestone

geomorphic units may be further subdivided into habitat types on basis of detailed geometry and substrate differences (Table 3).

Habitats

The term *"habitat"* as used here refers to space which abiotic factors determine as suitable for colonisation by biota. These factors primarily include substrate types and tidal levels. Other factors related to tidal levels include light attenuation, turbidity and salinity. Thus, the combination of substrate type and tidal oscillation provides a range of habitats for benthic organisms. The prism of marine water also is a habitat for a variety of nektonic and planktonic organisms.

The physiography and its configuration largely determine for example, whether a coastline is exposed or protected, eroding or advancing, or composed of plains or ridges and islands; substrates may vary from well oxygenated, mobile, clearly washed sand and gravel in high energy, exposed, beach environments to poorly oxygenated, muddy and bioturbated sediment in low energy, protected, mid-tidal environments; there may be a gently shelving seafloor, or a steeply plunging cliffed shoreline; or the submarine environment may be one of shallowly submerged irregular rocky areas or relatively deeply submerged flat plains.

Numerous habitat types occur within any given geomorphic unit. For example, within intertidal-flat units there can be distinguished a low-tidal muddy sand habitat, a low-tidal clean sand shoal habitat, a high-tidal mud (to muddy sand) salt-flat habitat. On rocky shores there can be distinguished cliffed shore habitats, bouldery shore habitats, fissured rock pavements, etc. The subdivision of geomorphic units into these habitats for biotic assemblages is summarised in Table 3 but the details form the basis for further papers that deal with specific biotic assemblages.

Biotic assemblages

Biotic assemblages are groups of organisms which occur in recognisable habitats; their grouping together is for convenience of description. There is a large range of habitat types, and with a given variation in physiochemical conditions such as wave action, salinity, sediment mobility, there is a corresponding large number of biotic assemblages that inhabitat the marine environment of the Dampier region. Most of the biota are markedly restricted to habitat type so that maps of habitats broadly represent boundaries and areas of assemblages.

Defining assemblages, however, can be problematic in that component species vary in abundance locally and one species dominant at one locality may be subordinant in abundance to another elsewhere, yet the overall composition and trophic relationships are essentially the same. The overlap of zones of animals and plants also make it difficult to assign a group of organisms to a particlular assemblage. Barnacles, for instance, occur in a mid-tidal zone of encrusting organisms but also extend down to the lower-tide levels of the adjoining assemblage. Thus, boundaries may be gradational or diffuse.

For purposes of this paper the biota of the archipelago has been aggregated into broad assemblages which tend to recur on, and are characteristic of, the broad categories of habitat.

Table 4

Benthic biotic assemblages and habitats

Assemblage	Geomorphic unit	Habitat	Tidal level
Oyster-barnacle	intertidal, rocky shore and intertidal limestone pavement	cliffed shore, fissured pavements or slopes, bouldery shore, limestone cliff and limestone pavement	intertidal
Coral	subtidal, rocky shore and subtidal limestone pavement	fissured rock pavement or slope, bouldery shore, limestone pavement	subtidal to depths of 10 m
Mangal	intertidal flat less commonly intertidal rocky shore	muddy sand flat, banks of tidal creeks, edges of spits, boulder shore	mid to high tidal
Notocallista-echinoderm	intertidal flat	sand flat and muddy sand flat	low tidal
Demersal fish-echinoderm-crustacean	subtidal plain	muddy sand/gravel sheet	subtidal
Donax-crustacean	intertidal beach	beach	mid to low tidal
Uca-cerithid	intertidal flat	salt flat	high tidal
Mictyris	intertidal flat	shoal, sand flat	low tidal
Uca-Macrophthalmus	intertidal flat	muddy sand flat	low tidal
Xanthid-sponge	intertidal, limestone pavement	low tidal limestone pavement	low tidal
Ocypode	intertidal beach	high tidal sand	high tidal
Seagrass	subtidal plain, intertidal flat	sand/gravel sheet, sand flat	subtidal, low tidal
Algae	shoal, embayment plain, subtidal rocky shore and limestone pavement	sand flat, sand/gravel sheet, bouldery shore, fissured pavement, limestone pavement	subtidal

The more widespread and important assemblages are: (1) oyster-barnacle, (2) coral, (3) mangal, (4) *Notocallista*—echinoderm, (5) demersal fish—echinoderm-crustacean, (6) *Donax*—crustacean, (7) *Uca*—cerithid, (8) *Mictyris*, (9) *Uca—Macrophthalmus,* (10) Xanthid—sponge, (11) *Ocypode*, (12) seagrass, (13) algae, (14) embayment fish and (15) pelagic fish-plankton.

A summary of the distribution of benthic biotic assemblages in relation to habitats is presented in Table 4. Figures 5, 6, and 7 present typical distribution patterns for these assemblages for several selected areas along the west coast of Burrup "Peninsula".

Oyster-barnacle assemblage.—This encrusting assemblage occurs on hard substrates such as igneous rock, limestone and mangrove roots and trunks in the intertidal zone (rocky shore and limestone pavement). The assemblage is zoned with different species and groups of species occurring at different heights. At the top of the intertidal zone an algae slick covers the rocks; at lower levels there is a narrow band of the milky oyster, *Saccostrea* sp. The coral rocky oyster, *Saccostrea cucculata*, forms a broader band below the milky oyster. Barnacles, *Tetraclita porosa* and *Chthamalus* sp. become more abundant below the oyster level and form a distinct zone. The worm-like vermetids form a zone at the lowest level of the intertidal zone. An algae turf occurs at the lower edge of this assemblage. Associated with the oysters and barnacles are a wide range of other molluscs such as bivalves, gastropods and chitons as well as crabs, polychaetes, amphipods and some small fish. Most of these species occur in the crevices in the rocks or the oyster clumps.

This assemblage, with variations, extends throughout the Dampier Archipelago. The major difference in the assemblages between Mermaid Sound and the outer islands of the archipelago is the replacement of the milk and coral rock oyster by the ocean oyster (*Saccostrea commercialis?*).

Coral assemblage.—The coral assemblage is totally subtidal occurring predominantly in water of 0-10 m depth. It is an encrusting assemblage on subtidal rocky shores and limestone pavements.

Corals are conspicuous and dominate this assemblage, but there is also a wide range of other fauna, such as seawhips, anemones, echinoderms, crustaceans, reef fish and molluscs including encrusting bivalves, infaunal bivalves and vagile gastropods. Sponges become more abundant where the assemblage is developed on limestone pavement.

Although there are no distinctly different coral assemblages in the various parts of the archipelago, some species of corals are confined to either the seaward reefs or to the more inshore reefs of the archipelago. There is some vertical zonation of the coral species, but it is not sufficiently pronounced that coral assemblages differentiate with depth.

However, the size of coral colonies, their abundance and the associated fauna do vary locally within the assemblage. The most marked variation is that between the assemblage on flat limestone pavement and the assemblage on sloping rocky shores. On the sloping substrates, the coral colonies reach a large size and are closely packed. In contrast, on flat limestone pavements the coral colonies are small and interspersed with a variety of other sessile invertebrates such as sponges, seawhips, zoanthids and anemones.

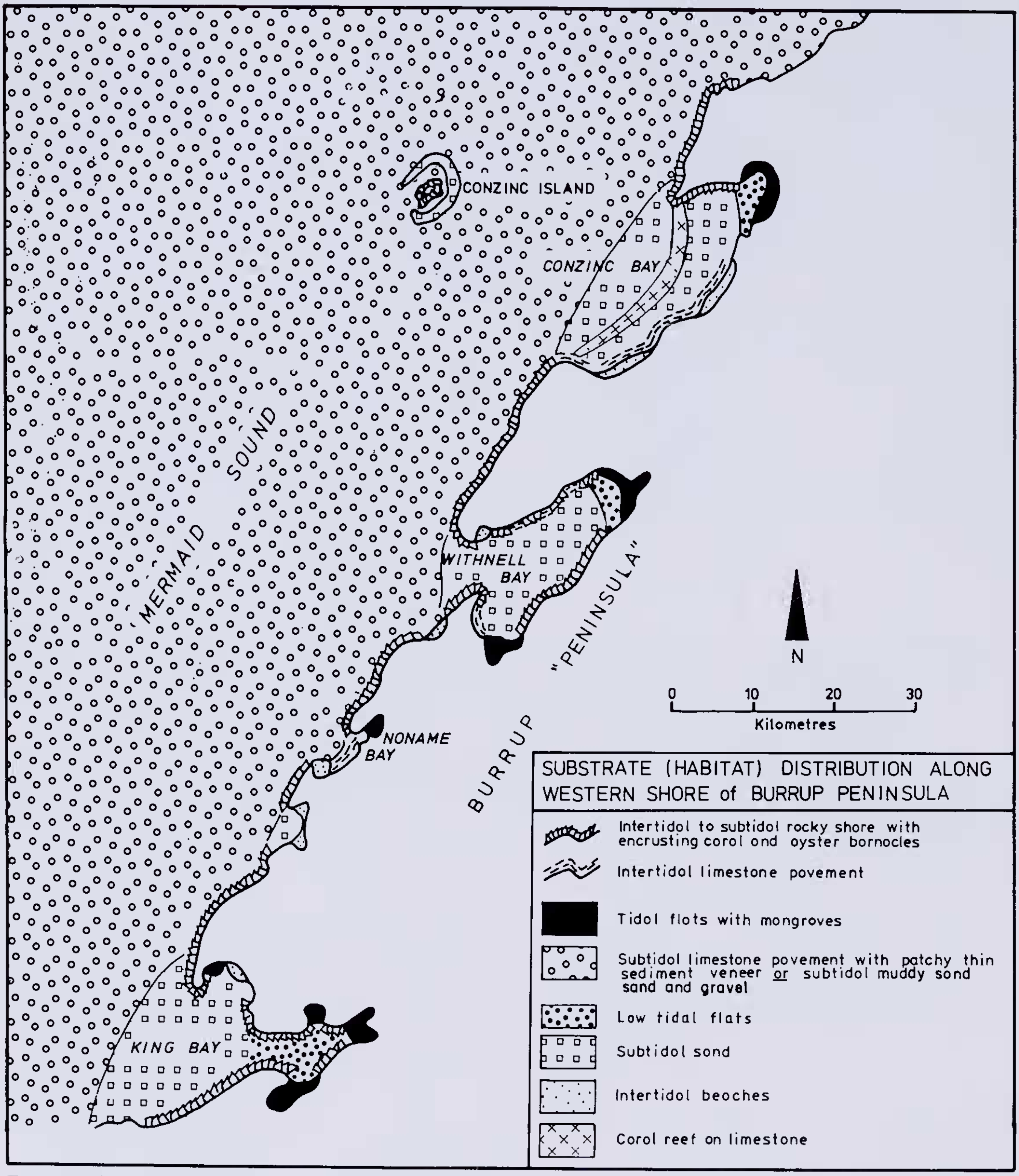


Figure 5.—Distribution of substrates and habitats (biotic assemblages) along the western shore of Burrup "Peninsula".

Mangal assemblage.—The mangrove vegetation assemblage is termed a mangal (MacNae 1968). Within this are mangrove trees and shrubs and a benthic fauna. The assemblage mostly inhabits intertidal flats of embayments between mean sea level and high water, though in some locations it occurs on rocky shores in embayments. Mangals vary from being wide tidal formations as at Searipple Passage and King Bay to narrow fringing formations as at Withnell Bay. In areas exposed to waves, mangals become progressively narrower (1 or 2 trees wide) and finally absent. The most luxuriant mangals occur at the inner portions of embayments where a combination of low-energy conditions and sedimentation provide a gently sloping tidal flat.

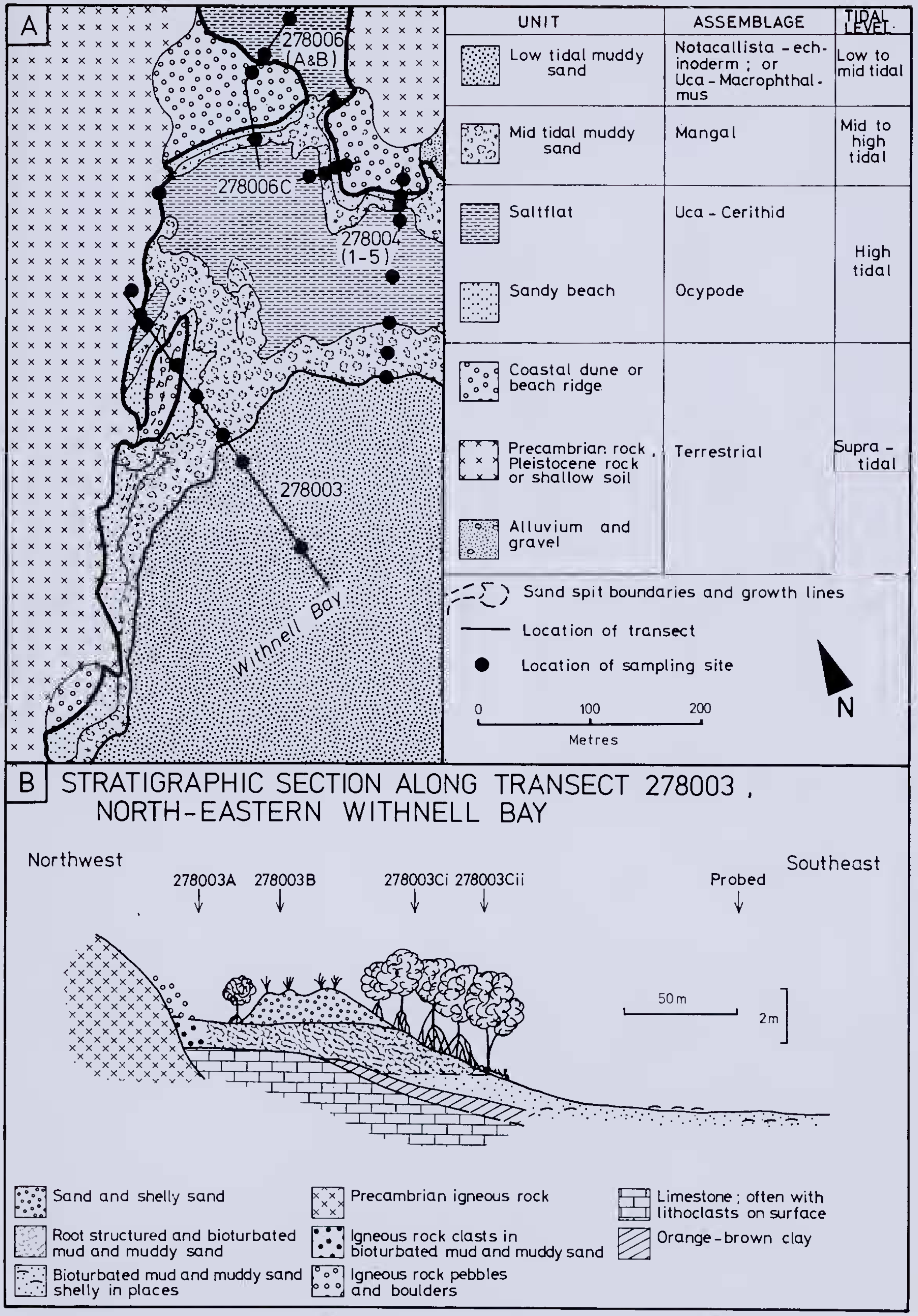


Figure 6.—A.—Distribution of habitats and biota in northeastern Withnell Bay. B.—Stratigraphic profile, northeastern Withnell Bay.

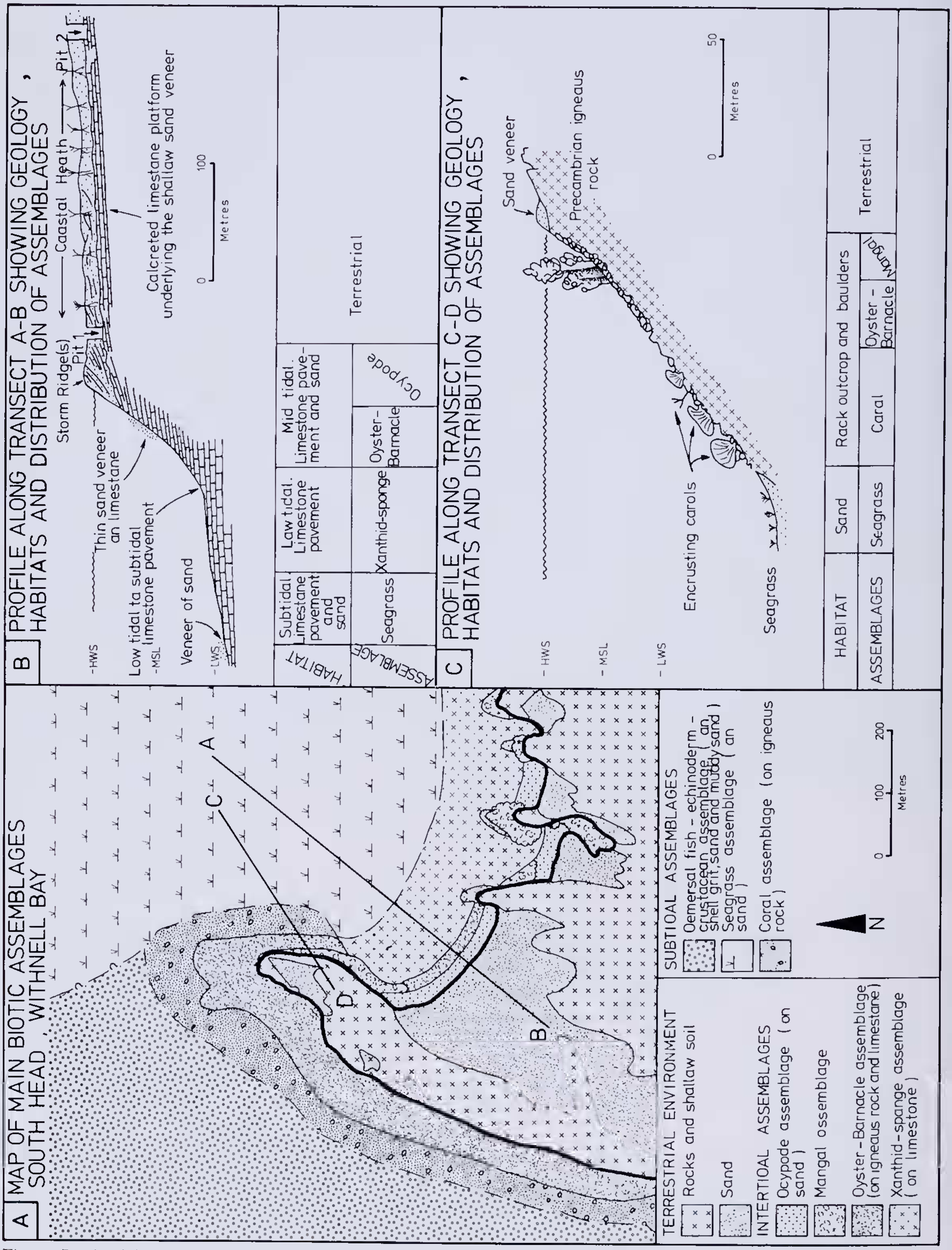


Figure 7.—A.—Distribution of biotic assemblages south head, entrance Withnell Bay; B, C.—Profiles showing distribution of substrate types and biotic assemblages.

Within the mangal there is a pronounced zonation of biota in response to tide levels, salinity and substrate types. *Avicennia marina* forms parklands and shrublands at about mean sea level. Interior parts of the mangal are closed forests of *Rhizophora stylosa* or mixed *Rhizophora, Avicennia* and rarer *Bruguiera exaristata*. Landwards parts of the mangal at about high-water spring level are shrublands of *Avicennia* with *Ceriops tagal*. In areas where there are spits, *Bruguiera* occurs with *Ceriops* and *Avicennia*.

Animals in the mangal include crustaceans (*Uca* spp. *Sesarma* spp., *Macrophthalmus*, alpheid shrimps, *Thalassina anomala, Epixanthus, Scylla serrata*); burrowing worms, vagile gastropods (*Terebralia, Cerithidea, Telescopium, Littorina* and *Nerita*); encrusting organisms (barnacles, bivalves and limpets), and miscellaneous biota such as gobioid fish and chitons. These animals occupy a variety of microhabitats in the mangal. A substantial proportion of the fauna are burrowing.

Notocallista—*echinoderm assemblage*.—This benthic assemblage colonises sand, muddy sand and gravel substrates in (low tidal) intertidal flats. It is composed almost entirely cf infaunal elements such as bivalves (*Notocallista, Anomalocardium, Circe, Fragum, Pinctada, Pinna, Placamen* and *Modiolus*), crustaceans, worms, brachiopods, burrowing anemones, and echinoderms. On the surface are the gastropods *Natica, Cerithium, Epitonium, Rhinoclavis, Cominella* and *Strombus*. Algae and gastropods (*Morula, Trochus*) may occur scattered on rocks or larger shells.

The sediment which these organisms colonise is thoroughly bioturbated. During high tide demersal fish and embayment fish invade the habitat which supports this assemblage and feed on the benthos.

Demersal fish-echinoderm-crustacean assemblage.—The demersal fish-echinoderm-crustacean assemblage inhabits substrates in water depths of 5-20 m deep in subtidal embayment plains, e.g. Withnell Bay, King Bay and Mermaid Sound. The assemblage is composed of a wide range of demersal fish (such as flatheads, flounders, catfish, eels and rays), echinoderms, polychaetes, crustaceans, gastropods and bivalves. Some of the fish from this assemblage probably move onto the intertidal flats during high tide. Much of the gross variation within the assemblage can be related to substrate types and future work may result in further division of this assemblage.

Donax—*crustacean assemblage*.—Exposed beaches occurring in small embayments and tombolo settings support an infaunal assemblage of crustaceans and bivalves (mainly *Donax*) and surface gastropods. On such beaches there is zonation within the assemblage in relation to tidal level. Mid-low tidal zones have the crabs *Scopimera* and *Mictyris*, polychaetes, surface gastropod *Nassarius dorsata* plus infaunal bivalves (*Donax*); low tidal zones have the crabs *Matuta* and, in more oceanic settings, *Callapa*.

Uca—*cerithid assemblage*.—This assemblage inhabits high-tidal salt flats shoreward of mangroves on intertidal flats. The surface of the substrate may be caked with a film of blue-green algae. Fauna includes the burrowing crabs *Uca* spp., *Metopograpsus* and *Sesarma*, and, in addition, the gastropod *Cerithium* sp.; salt bushes occur on higher parts of the flat.

Mictyris *assemblage*.—This is a benthic assemblage dominated by the soldier crab *Mictyris* which inhabits low-tidal sand shoals on intertidal flats. Bivavles, brachiopods. echinoderms and the sand-bubbler crab *Scopimera* form a minor component.

Uca—Macrophthalmus *assemblage.—This* assemblage is dominated by crabs *Uca* spp. and *Macrophthalmus*, and occurs on low-tidal muddy-sand flats and shoals of intertidal flats. Bivalves, echinoderms and worms form a minor part of the assemblage.

Xanthid-sponge assemblage.—The xanthid-sponge assemblage occurs on low-tidal limestone pavements in embayments. The assemblage includes several species of xanthids (*Pilumnus, Atergatis*), encrusting to erect sponges, tube worms, gobioid fish, bivalves (*Tridacna, Barbatia*), scattered corals and algae.

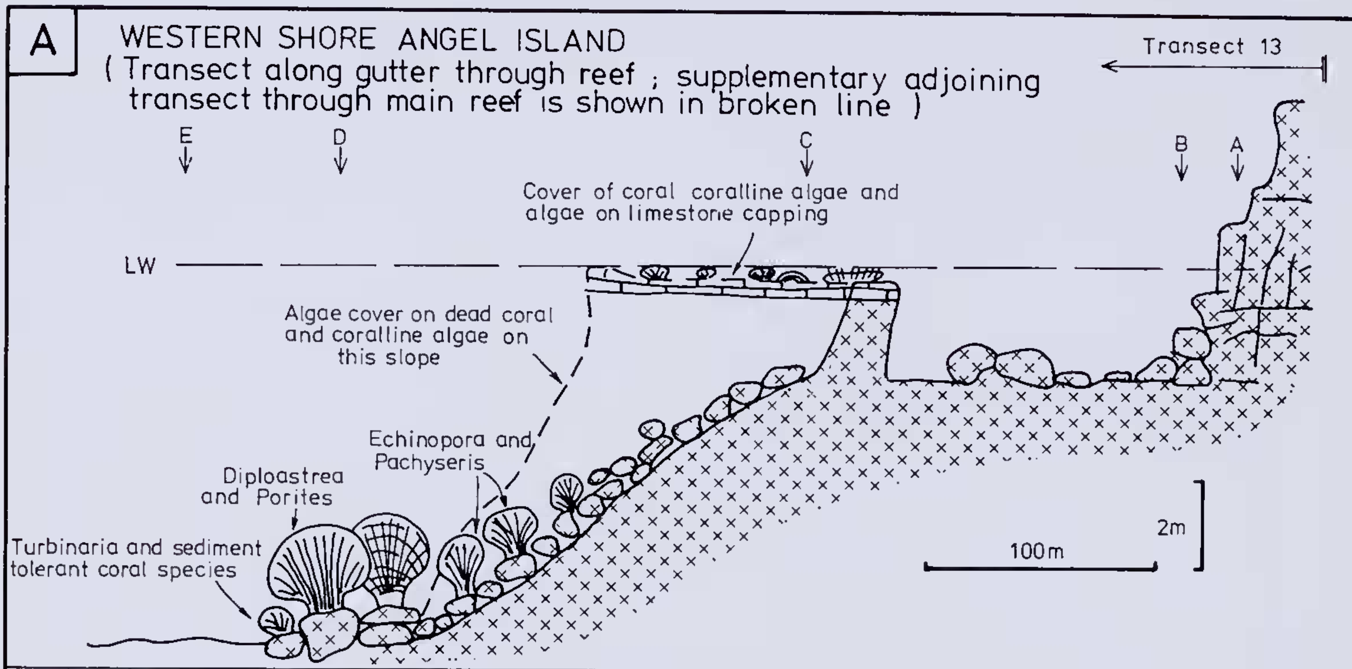
Ocypode *assemblage*.—The *Ocypode* assemblage occurs on high-tidal to supratidal parts of sandy beaches and spits. Fauna includes the ghost crab *Ocypode*, hermit crabs *Coenobita* and amphipods.

Seagrass assemblage.—This assemblage occurs on low-tidal sand flats and shallow subtidal embayment plains with substrates of sand and mud-sand; the assemblage typically occurs in the larger bays of Burrup "Peninsula". The seagrass *Halophila* (*H. ovalis, H. decipiens* and *H. spinulosa*) is sparse, but occurs throughout this assemblage. In some areas of shallow water, green algae are abundant during winter. Invertebrates (including echinoids, holothurians, molluscs, crabs) and demersal fish are locally abundant.

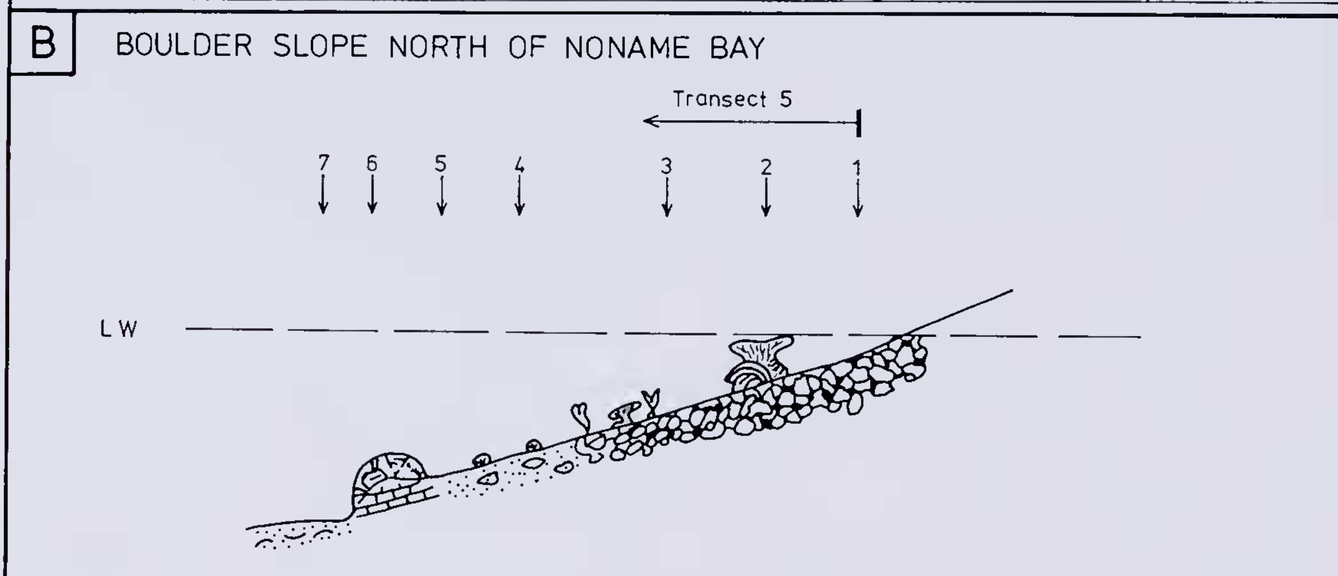
Algae assemblage.—Macroscopic algae colonise various types of subtidal substrates in the shallow waters of the archipelago. These substrates include sand/gravel sheets of embayment plains as well as shoals, bouldery shores and limestone pavements. The species, diversity, abundance and distribution of algae within the archipelago varies markedly in response to habitat, abundance of herbivores and seasonal and sporadic phenomena (such as cyclones). At a later stage with more detailed work this assemblage may be further subdivided.

The shoals of the outer archipelago contain the greatest diversity, and amount of algae of any of the areas examined. However, these characteristics were not consistent throughout this habitat. In places, brown algae were the most abundant algae group with the genus *Dictyopteris* being most frequently observed. The green algae were dominated by the articulated corallines. *Halophila spinulosa* was the most abundant species of angiosperm. Whilst algae were the main biotic components on shoals, areas of barren sand ridges occurred in places. Other organisms which occurred in the algal assemblage on shoals included molluscs, corals, echinoderms, crabs and fish.

Elsewhere plant cover was less and brown algae, whilst still abundant and diverse, were dominated by fucoid species. Similarly, amongst the red algae, the non-corallines were more abundant. In other places on limestone pavements where there was no sand veneer the algae were dominated by crustose corallines and algal turf (*Jania* sp.).



BIOTA	Barren	Coral bommies	Coral and algae corals decreasing in abundance upslope		Barren	Oyster - Barnacle
SUBSTRATE	Rippled sand	Igneous rock boulders		Igneous rock with limestone capping	Igneous rock boulders and sand	Rocky shore and boulders



BIOTA	Demersal fish Molluscs	Coral bommies	Scattered small corals	Abundant coral	Coral with occasional bommies	Oyster - Barnacle
SUBSTRATE	Shelly gravel	Limestone	Sand and gravel Uncommon boulders	Igneous rock boulders decreasing in size downslope		Igneous rock boulder frame ; interstitial pebbles

2m
20m

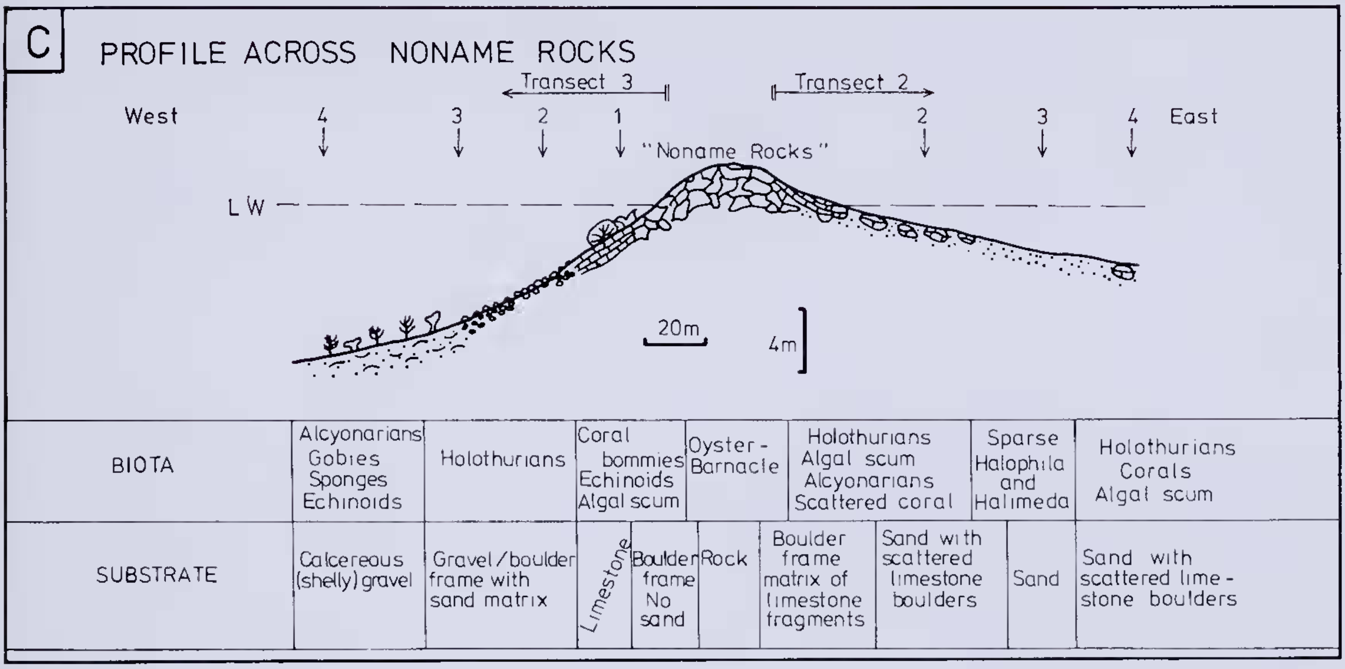


Figure 8.—Profiles (along transects 2, 3, 5 and 13; see Fig. 2A) showing distribution of substrates and biota.

The algal assemblage which occurred in protected embayments such as Conzinc Bay was also dominated by the brown algae; *Sargassum, Dictyopteris* and *Padina* being the more abundant genera. Other genera of brown algae (*Zonaria, Dictyota* and *Turbinaria*) occurred in minor abundance.

Embayment fish assemblage.—The embayments along Burrup "Peninsula" support an abundant and diverse assemblage of fish. Although these fish move between embayments and are consequently also found outside the embayments, they are most abundant, and appear to spend a substantial amount of their time within the embayments. The composition of the fish assemblage varies to some extent depending on whether the embayment is small, exposed and has a sandy beach, or is large and protected with extensive sand-mud flats and mangroves.

More fish occurred on the sand-mud tidal flats around the margins of the larger bays than on the sandy beaches of the small, exposed bays. This is probably because the sand-mud flats and mangrove-based detritus of the larger bays supported a rich benthic fauna which in turn provided a food source for fish.

Additionally the larger bays supported a greater total number of fish because of their greater area. Most juvenile fish also occurred in the shallow waters of the larger embayments. The shallow waters of the embayments also provided a refuge for the embayment fish from larger predatory fish.

Pelagic fish-plankton assemblage.—The open water areas of the Dampier Archipelago contain fast-swimming predatory fish such as sharks, mackerel, cobia, trevally and queenfish. Small baitfish were also plentiful in the surface water. Mackerel were either planktivorous or piscivorous depending on the food sources present in the open water. However, most of the other fish of open waters moved onto the sand-mud tidal flats of the embayments during high tides and these shallow water areas probably provided the food source for many fish. The other major component of this assemblage is the plankton. Phytoplankton which are present in low densities throughout the year, are particularly obvious when blooms occur. Blooms of dinoflagellates are responsible for producing "red-tides" which occur periodically through the spring, summer and autumn.

Distribution in the archipelago

The biotic assemblages and habitats in the archipelago have been mapped both extensively at the regional level and intensively at the local level. Distribution of the broad habitats and their associated assemblages are illustrated in Figure 5. This shows most habitats/assemblages are widespread along the shore of Burrup "Peninsula". Virtually every shoreline in the archipelago has exposed and semiprotected settings within which are tidal and subtidal (rocks, limestone, sand/gravel and muddy) substrates. More detailed distribution of habitat/assemblage is illustrates in maps and transects of selected areas and these are typical representations of the regional picture (Figs. 6-8). These areas show a complex distribution pattern in the nearshore and tidal environments.

This variability reflects firstly the heterogeneity of soils and landforms that existed prior to the post-glacial Holocene transgression, and secondly the types of physical processes (erosion versus sedimentation) that are operating at present along the nearshore and shoreline environments.

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